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Investigation of Models for Large-Scale Meteorological Prediction Experiments

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INVESTIGATION OF MODELS FOR LARGE-SCALE METEOROLOGICAL PREDICTION EXPERIMENTS

Introduction

The principal activities of The City College group during the past year were all related to the evaluation of monthly mean forecasts and climate simulations generated at the Goddard Institute for Space Studies (GISS) with the global "climate model" (Hansen, et al.1979). This work was conducted mainly at GISS, and in close collaboration with the GISS atmospheric modeling team. All computations, including plots, were carried out at GISS, which also provided office space for the principal investigator and 2 or 3 graduate student research assistants.

Graduate assistants employed on the project during the past year included Ronald Filadelfo (who completed his master's program at The City College and resigned August 31, 1979 to pursue a Ph.D. program in oceanography at SUNY-Stony Brook), Zaphiris Christidis, and Michael Dennis who joined the group in July 1979. The City College project has been ably assisted also by two GISS employees, Jesus J. Notario (who resigned in October 1979) and Robert Klugman.

Most of the forecast and climate simulation experiments analyzed were conducted with a "medium" mesh (8° of latitude by 10° of longitude) 7-layer version of the climate model, referred to as MX500M7. However, experiments have also been run with 9- and 12- layer versions and with a "fine" mesh (4° of latitude by 5° of longitude). In the course of the model development, various modifications were introduced which delayed the forecast verifications for several months, and which also rendered many early experiments obsolete.

The evaluation program has concentrated on two kinds of outputs: (a) monthly mean forecasts for the months of October 1976 through February 1977, generated from global initial conditions for the first day of each month provided by the National Meteorological Center (NMC) and the National Center for Atmospheric Research (NCAR), and (b) a "model climatology" generated by running the model for 5 simulated years from one set of initial conditions (1 December 1976) and then averaging the 5 outputs for each of the 12 calendar months. The forecasts were evaluated against the corresponding monthly mean NMC/NCAR data for the 5 specific months above, while the model climatology was compared with an "observed climatology" provided by NCAR and based on data archived at the National Climate Center (NCC) in Asheville, N.C.

This has been primarily a synoptic evaluation,with attention focussed mainly on three field: 850 mb temperatures (T8), 500 mb geopotential heights (Z5), and sea-level pressures (SLP). The results are presented in map form, and also numerically in terms of various measures of agreement, including root-mean-square errors, gradient (S1) skill scores, and correlation coefficients between forecast and observed fields, or between model and observed climatologies. The observed and model-generated synoptic fields were also subjected to spherical harmonic analysis and compared in terms of the principal modes.

One paper was published in 1979 (Spar, J. and R. Lutz, 1979: Simulations of the monthly mean atmosphere for February 1976 with the GISS model. Monthly Weather Review, 107, 181-192), and the following technical reports, as well as the semi-annual status report, were distributed:

Spar, J., 1979: Interim report on forecasting experiments with a climate model. 4 pp. June 1979.

Spar, J. and R. Klugman, 1979: Note on decay of predictability in forecast experiments with the GISS climate model. 3 pp June 1979.

Spar, J., R. Klugman and J. J. Notario, 1979: Effects of horizontal and vertical resolution in climate model forecast experiments. 8 pp. July 1979.

Christidis, Z. and J. Spar, 1979: Spherical harmonic analysis for verification of a global atmospheric model. 9 pp. August 1979

An invited paper on "Prediction Experiments with a Coarse-Mesh Global Model" was presented by J. Spar at the Climate Diagnostics Workshop in Madison, Wis (16-18 October 1979), and will be published in the proceedings of the Workshop.

A master's thesis by R. Filadelfo ("The Effect of Sea Surface Temperature Anomalies on Monthly Mean Simulations with a Coarse Mesh Global General Circulation Model") was accepted by The City College in October 1979.

Monthly Mean Forecast Experiments with the Climate Model

The 8° x 10° climate model was run using global NMC/NCAR initial conditions for 00 GMT on the first day of each of 5 months, October 1976 through February 1977, a period of severe weather over the eastern United States. Initially a 9- level version of the model (No.252) was used for these experiments, and later the forecasts were repeated with a 7- level version (No. 444). As reported in the Semi-Annual Status Report of the project (June 1979), neither set of monthly mean forecasts exhibited skill equal to that of climatology, indicating that these versions of the model were neither predicting climatology nor correctly predicting the anomalous departures from climatology of the monthly mean fields over the globe or over the Northern Hemisphere.

The low skill of the monthly mean forecasts is, of course, related to the rapid decay of predictability. This is illustrated by the results of an evaluation of the forecast history generated by model No. 444 in which the 5 forecast runs were averaged over periods of the first 5, 10, and 15 days, as well as the whole month. The S1 skill scores and rms errors over the Northern Hemisphere were computed for each averaging period, and averages of these values for the 5-month experiment are shown in figure 1. It is apparent that most of the forecast error (about 90%) is generated in the first 15 days of the month.

The monthly mean forecasts were later repeated with model number MX500M7 (another 8°x10° 7- level version) with similar results, as shown by the forecast statistics for the Northern Hemisphere in Table 1. The discrepancies between the predicted and observed monthly mean synoptic fields are illustrated for the month of December 1976 in figures 2-4, with the forecast fields at the top and the observed fields at the bottom. While the forecast fields of T8 and Z5 are realistic in appearance, there are obvious errors in the simulations of the large-scale temperature and contour patterns. The discrepancies between the forecast and observed SLP fields are, of course, even more apparent.

The forecast errors do not appear to be highly dependent on the grid size employed. This is indicated by a comparative run for December 1976 that was carried out with the same 7- layer model (No.444), but with two different grids: 8°x10° and 4°x5°. As shown in Table 2 below, the rms errors, which are not scale-dependent, are very similar for the two grids. The S1 skill scores, which are seen to be highly scale dependent, are actually higher (i.e., worse) for the finer grid,

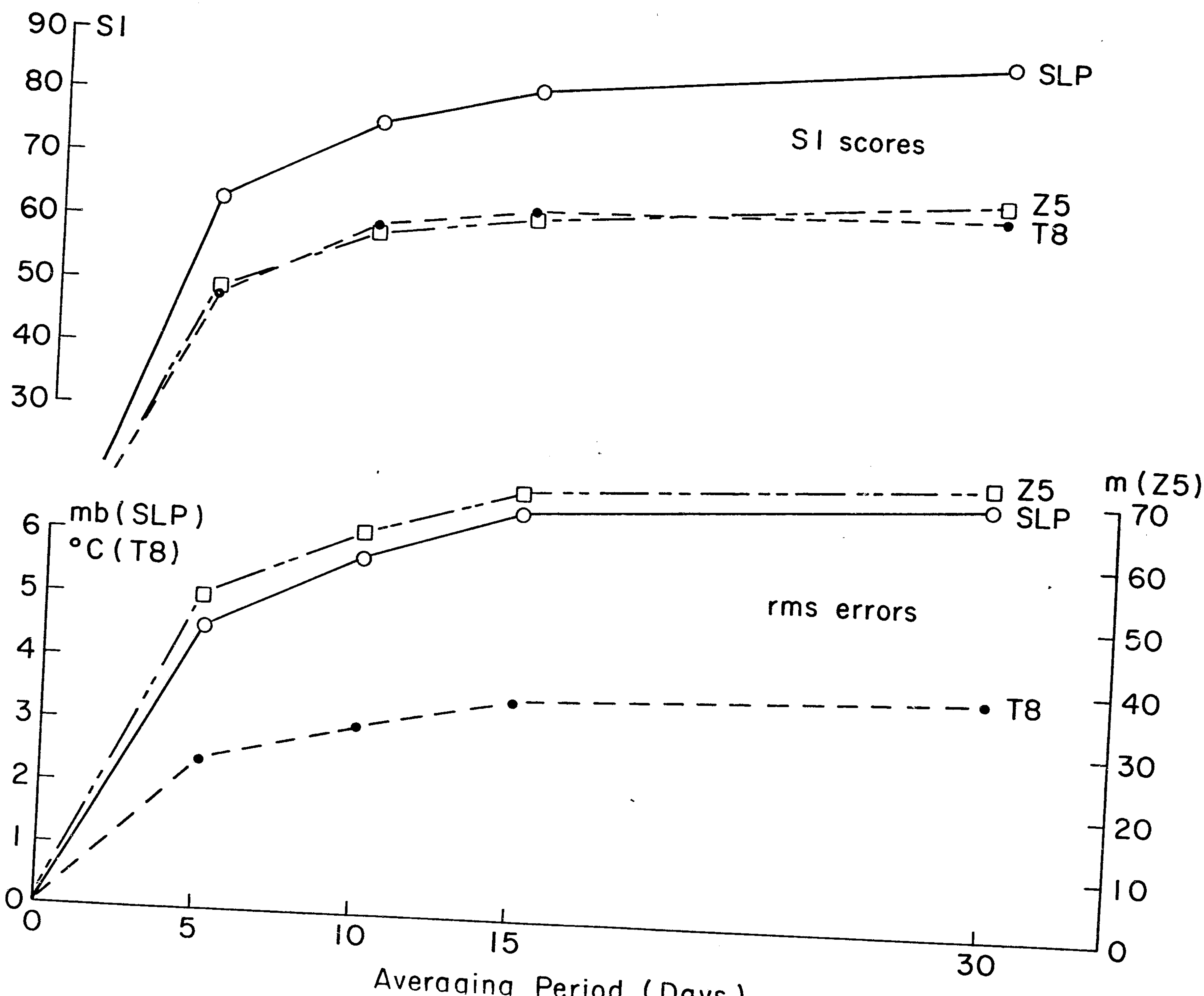
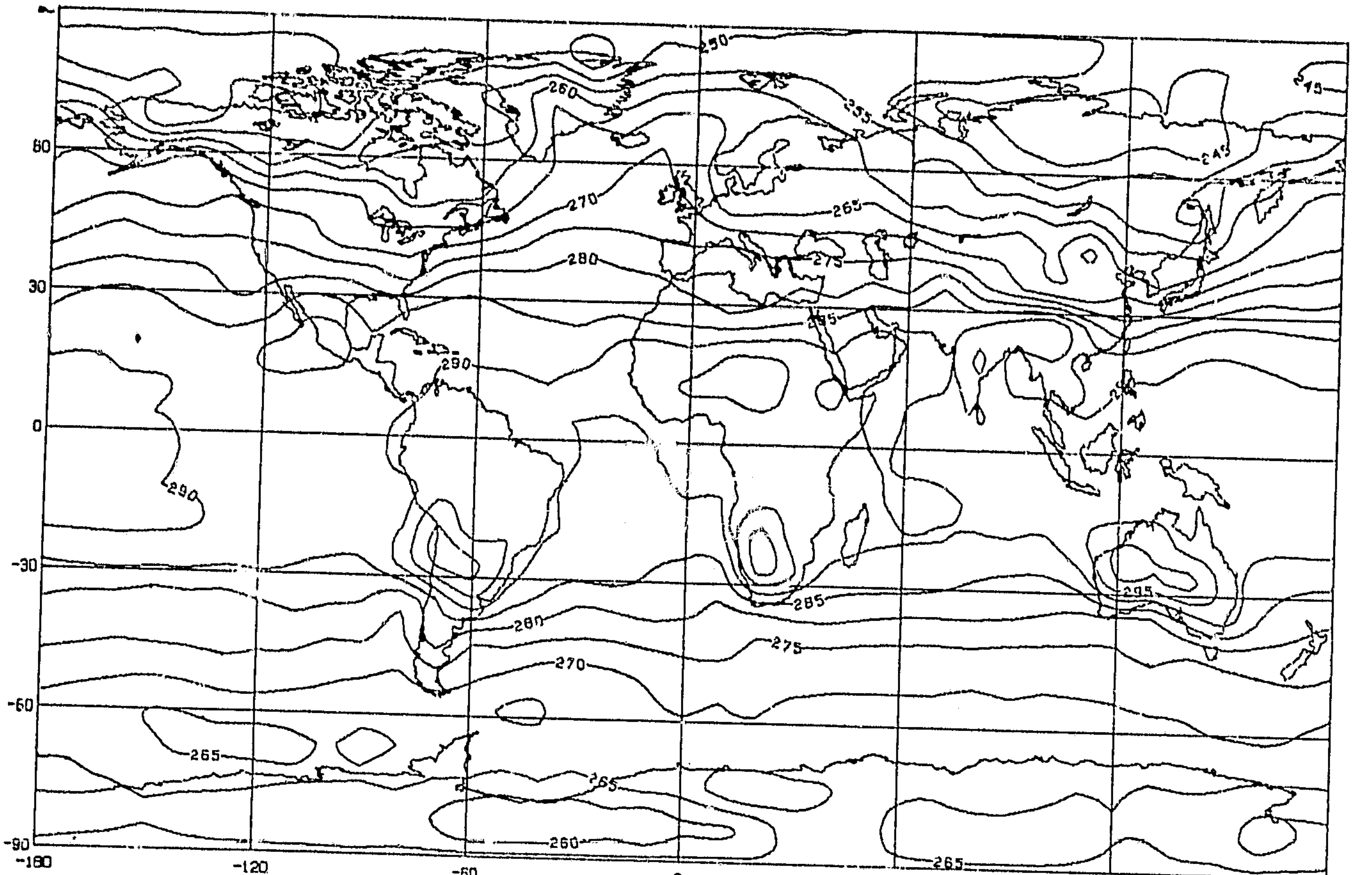
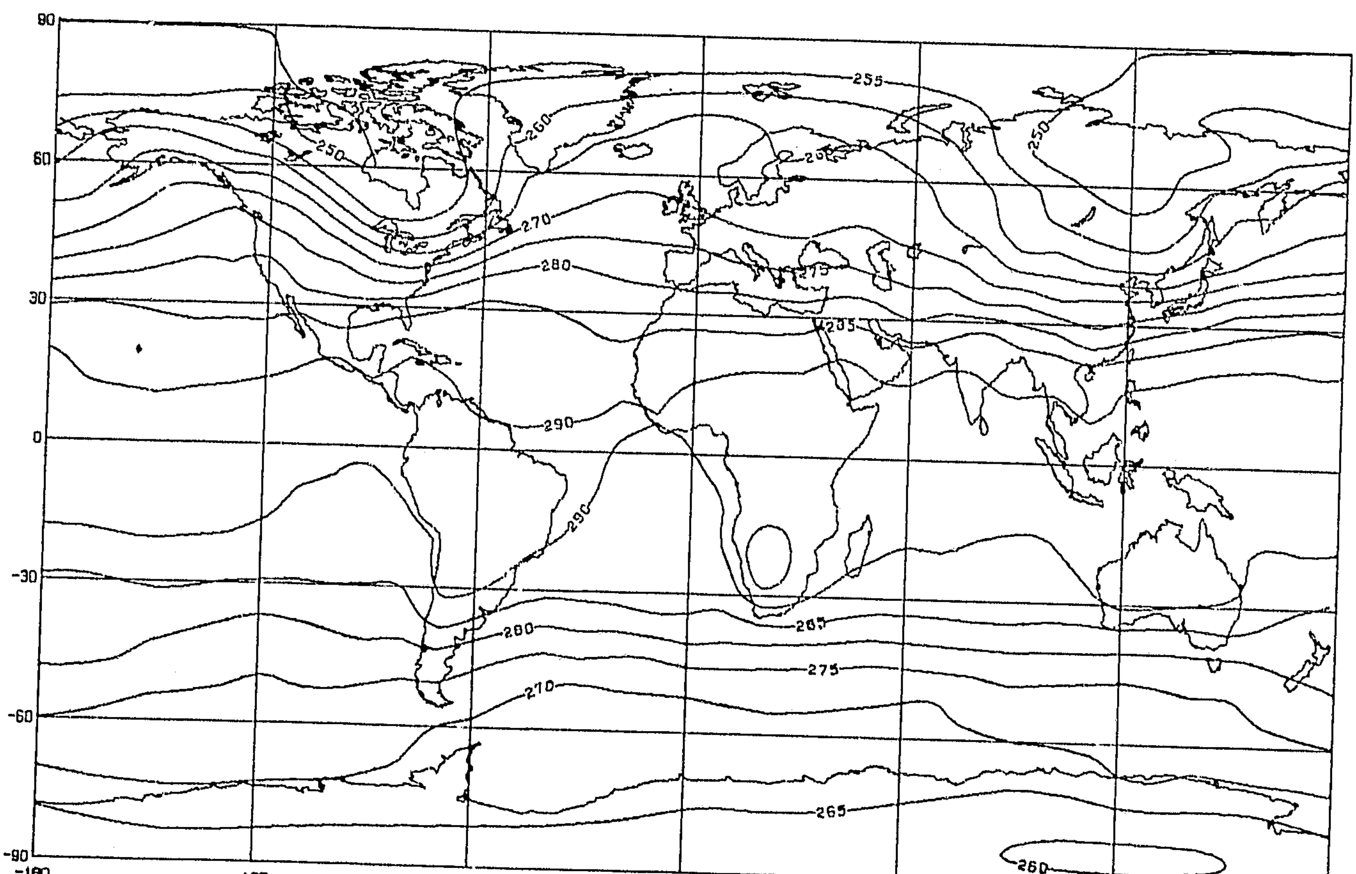

90
80
70
60
50
40
30
SI
SLP
SI scores
Z5
T8
mb (SLP)
°C (T8)
6
5
4
3
2
1
0
m (Z5)
70
60
50
40
30
20
10
0
Z5
SLP
rms errors
T8
0
5
10
15
30
Averaging Period (Days)

Fig. 1

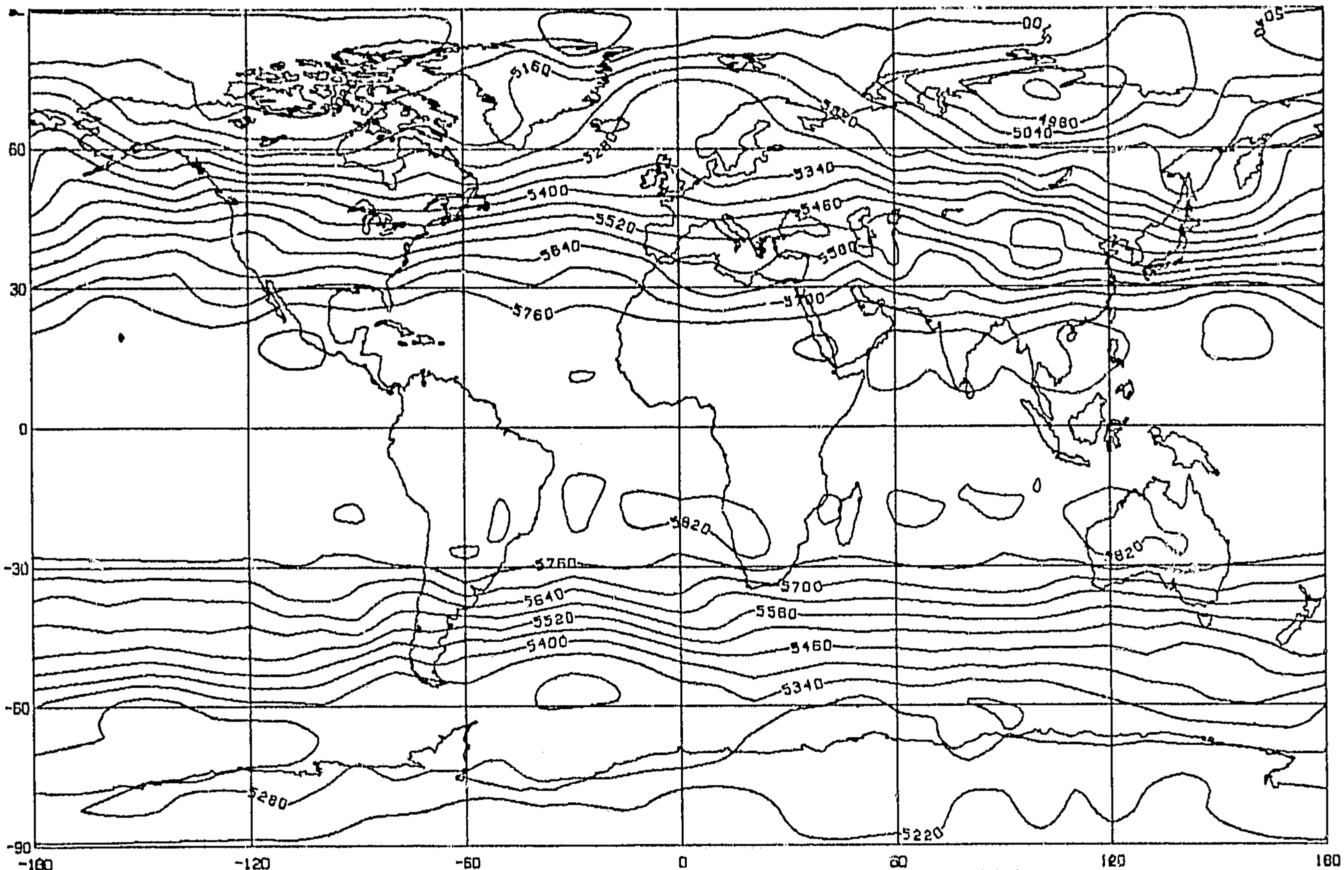


DECEMBER FORECAST 850MB TEMPERATURE

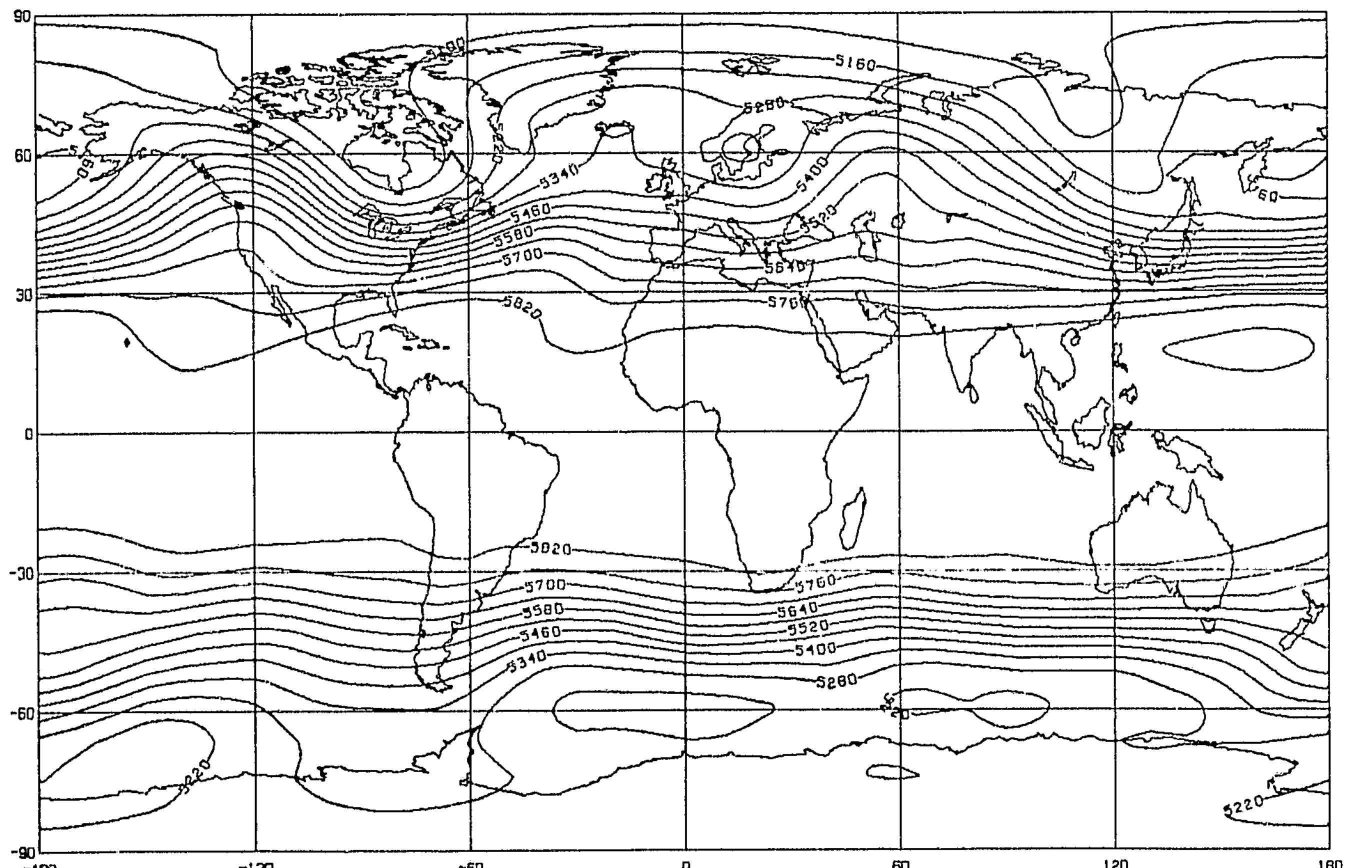


DECEMBER OBSERVED 850MB TEMPERATURE

Fig. 2

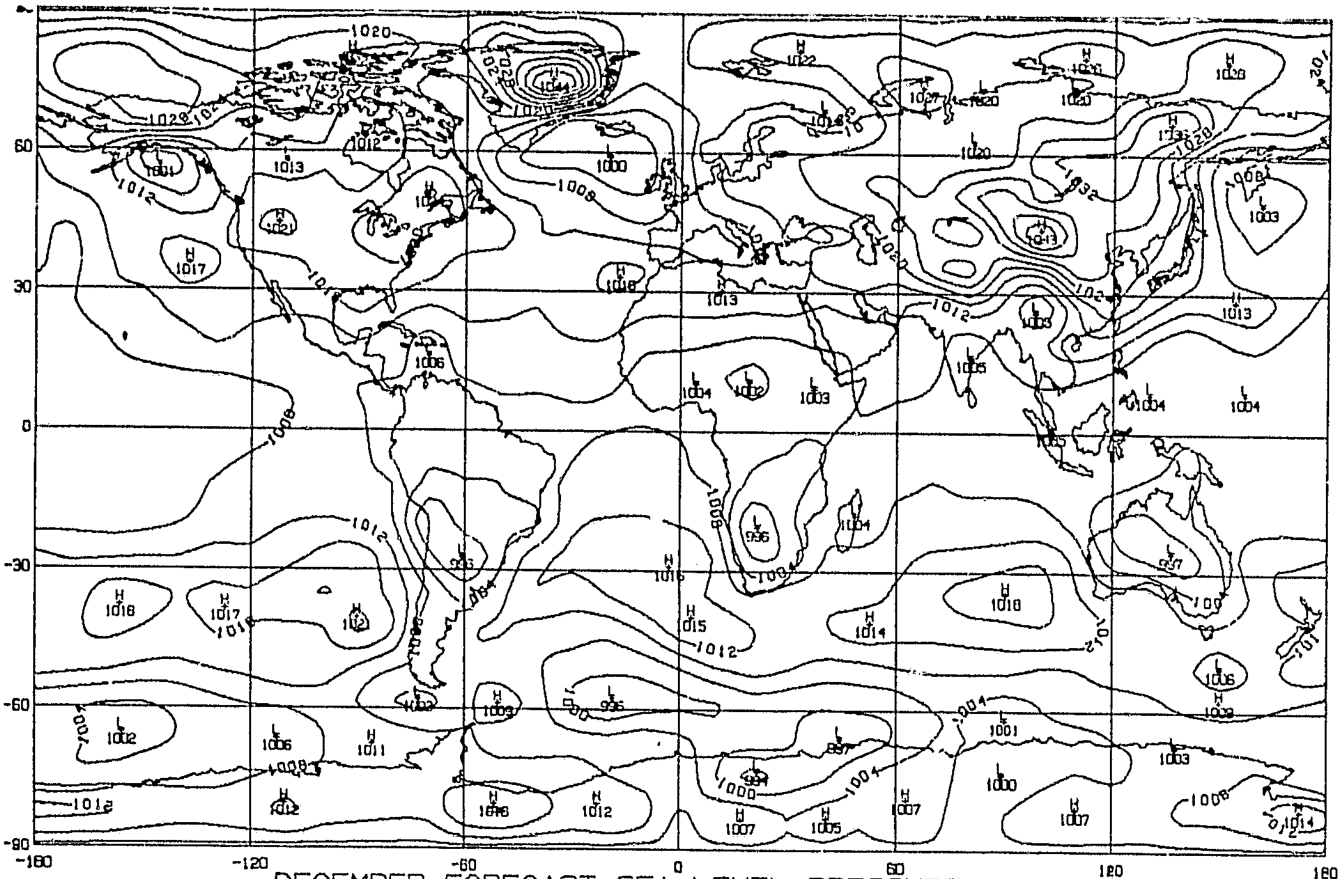


DECEMBER FORECAST 500MB GEOPOTENTIAL HEIGHT

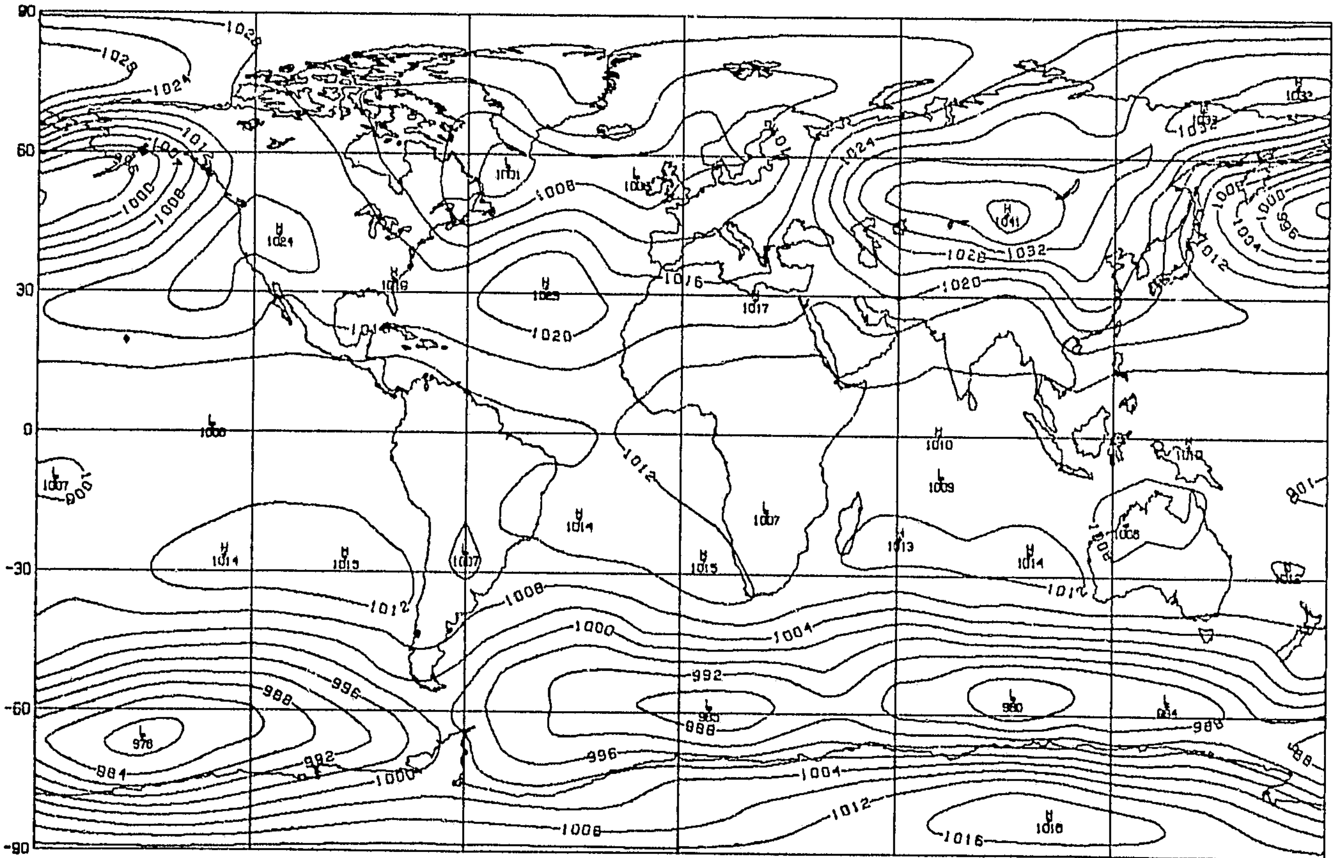


DECEMBER OBSERVED 500MB GEOPOTENTIAL HEIGHT

Fig. 3



DECEMBER FORECAST SEA LEVEL PRESSURE



DECEMBER OBSERVED SEA LEVEL PRESSURE

Fig. 4

Table 1. Forecast statistics for the Northern Hemisphere with model MX500M7 (M), October 1976-February 1977, compared with "forecasts" of climatology (C)

	T8-M	T8-C	Z5-M	Z5-C	SLP-M	SLP-C
	October 1976					
rms error	3.2°C	2.2°C	62m	39m	6.0mb	3.0mb
S1 score	65	49	63	47	99	65
	November 1976					
rms error	3.8°C	2.1°C	72m	40m	7.1mb	2.9mb
S1 score	66	47	66	42	90	53
	December 1976					
rms error	3.4°C	1.9°C	71m	43m	5.8mb	3.5mb
S1 score	62	39	63	43	84	51
	January 1977					
rms error	4.3°C	2.7°C	91m	73m	6.8mb	5.9mb
S1 score	61	51	66	57	83	64
	February 1977					
rms error	4.2°C	2.3°C	80m	55m	7.5mb	4.4mb
S1 score	68	43	60	48	85	62

but the difference is just about accounted for by the scale-dependence. The correlation coefficients, r, between the forecast and observed deviations from climatology (i.e., between anomalies), are higher for the finer grid, but the scale-dependence of this statistic has not been determined. The statistics for a forecast of climatology on the two grids, which are also included in the table, indicate that the errors relative to climatology are similar on the two grids.

Table 2. Forecast statistics for December 1976, Northern Hemisphere, on 4°x5° and 8°x10° grids with model No. 444. Rms errors and S1 scores for climatology are also shown for comparison.

	T8		Z5		SLP	
	4x5	8x10	4x5	8x10	4x5	8x10
Model 444						
rms	3.1°C	3.2°C	66m	66m	5.6 mb	6.3mb
S1	93	54	89	63	104	87
r	+0.36	+0.23	+0.14	+0.02	+0.41	+0.30
Climatology						
rms	1.9°C	1.9°C	43m	43m	3.5 mb	3.5 mb
S1	75	39	75	43	86	51

The fact that the model does not generate a monthly mean forecast that is better than (or even as good as) climatology, suggests that the model's "climatology" may be quite different that that of the real world. If this is so, then the forecast state for a given month would obviously correlate poorly with the observed. However, it is possible that, even if the two climatologies are different, the response of the model to changes in initial conditions might still resemble that of nature. As a test of this hypothesis, correlation coefficients, r*, were computed between the observed monthly anomaly, i.e. the observed deviation from the real climatology, and the model's forecast anomaly, i.e. the deviation of the forecast from the model's monthly climatology. This differs from the correlation coefficient, r (as, e.g., in Table 2), for which both observed and forecast anomalies were computed relative to the same real climatology. (The calculation of r* necessitated the generation of a model climatology, which is discussed in further detail later in this report.)

Table 3 shows the results of the verification of the 5 monthly mean forecasts generated by model MX500M7 in terms of the two correlation coefficients, r* and r. If, despite any differences between the two climatologies, the model correctly simulated the response of the atmosphere to the given initial conditions, r* should be higher than r. However, this is seen to be true in only 7 out of the 15 trials, and the mean values of r* and r are both almost equally low. Thus, the hypothesis that model correctly simulates response to initial conditions does not appear to be supported by this experiment. (An alternative experiment, in which the model is initialized with data representing the same deviation from the model climatology as the actual deviation of the observed initial state from the real climatology, has not yet been carried out.)

Table 3. Correlation coefficient, r*, between model forecast anomaly (forecast - model climatology) and observed anomaly (observed - real climatology) compared with correlation coefficient, r, between forecast and observed anomalies relative to the real climatology. Northern Hemisphere Model MX500M7.

Month	Field	r*	r
October 1976	T8	+0.08	+0.56
	Z5	+0.39	+0.30
	SLP	+0.20	+0.39
November 1976	T8	+0.05	+0.20
	Z5	+0.17	-0.11
	SLP	+0.03	-0.21
December 1976	T8	-0.05	+0.15
	Z5	+0.14	-0.03
	SLP	+0.28	+0.38
January 1977	T8	+0.00	+0.07
	Z5	+0.34	+0.17
	SLP	+0.32	+0.36
February 1977	T8	+0.07	+0.20
	Z5	+0.14	+0.12
	SLP	+0.17	+0.05
Mean		+0.16	+0.17

Sea-Surface Temperature (SST) Anomalies

The influence of SST anomalies on monthly and seasonal atmospheric states is considered to be an important one by many subjective and statistical long-range weather forecasters. However, efforts to demonstrate such atmospheric forcing by anomalous surface boundary conditions through the use of dynamical models have generally yielded ambiguous results, mainly due to model deficiencies (low forecast skill) and the dubious quality of the SST data. Nevertheless, an effort was made to test the response of the GISS climate model to SST anomalies by computing two parallel forecasts from identical initial conditions, but with the usual monthly climatological SST's used in one run (the "control" forecast) and the "observed" monthly mean SST's used in the other (the "anomaly" forecast) as ocean surface boundary conditions.

Daily global SST data, derived from NOAA satellite scanning radiometer measurements (Brower, et al., 1976), are available on tape from NMC on two 256 x 256 polar stereographic grids. These values were averaged over each month, the monthly mean stereographic values were interpolated to a 1° latitude-longitude grid, and the spherical grid data were then averaged over 8°x10° grid boxes of the model to obtain a suitably defined observed monthly mean SST field for each forecast. The use of such observed SST's in a forecast, of course, implies the hope that in some future interactive air-sea model it may be possible to predict accurately the SST field.

Unfortunately, the satellite-derived SST's are now known to contain some rather serious errors (Barnett et al., 1979) which affect even the monthly averages, and as a result the validity of this experiment is rather questionable in terms of the influence of SST's on forecast skill.

Nevertheless, the experiment does reveal something about the response of the model to SST anomalies, even though the latter may be spurious.

The global field of SST anomalies based on the satellite data for December 1976 is shown in figure 5, and the corresponding difference maps for the anomaly-minus-control forecasts of T8, Z5, and SLP are shown in figures 6-8. The dominant SST anomalies are warm water off the east coasts of North America and Asia near latitude 45°N, and cold water in the tropical North Pacific Ocean. Over the warm pools the model produces higher 850 mb temperatures and 500 mb heights and lower sea-level pressures, but there is apparently little response to the cold water in the tropics. Large differences between the anomaly and control forecasts are found north of latitude 45° N. However, the "noise level" of the model atmosphere in high latitudes (based on the standard deviations for each month of the 5 year model climatology run described below) was found to be so large that no statistical significance could be attached to the anomaly -control differences in that region. Where the "noise level" is low (the tropics), the "signal" (anomaly - control difference) is also small.

(Further details of the SST anomaly experiment may be found in an M.A. thesis by R. Filadelfo: "The Effect of Sea-Surface Temperature Anomalies on Monthly Mean Simulations with a Coarse-Mesh Global General Circulation Model".)

FIGURE 5: DECEMBER 1976 SST ANOMALIES (°C)

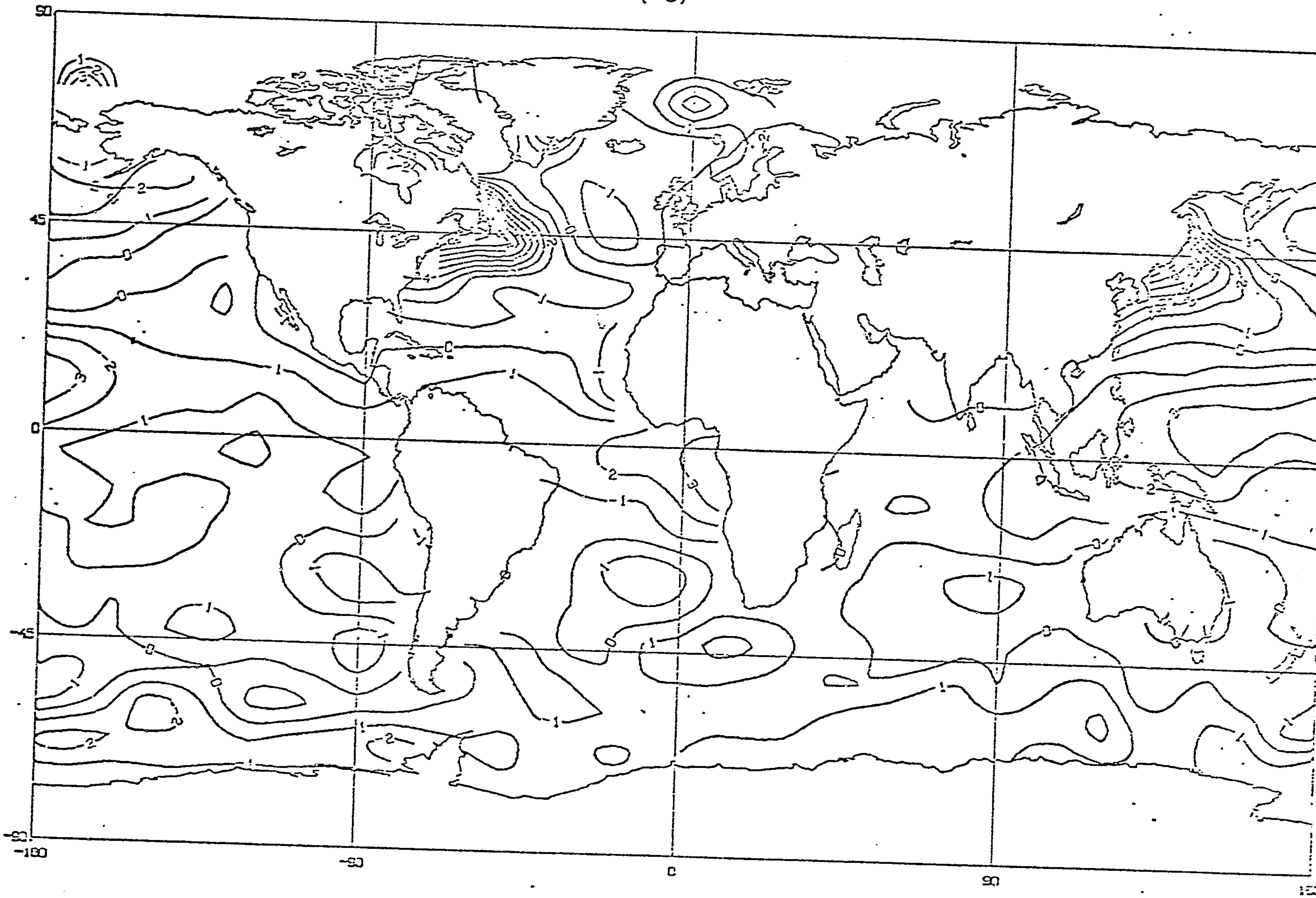


FIGURE 6

ANM-CNT FCSTS TEMPERATURE AT 850 MB

FIGURE 7

ANM-CNT FCSTS GEOPOTENTIAL HEIGHT 500 MB

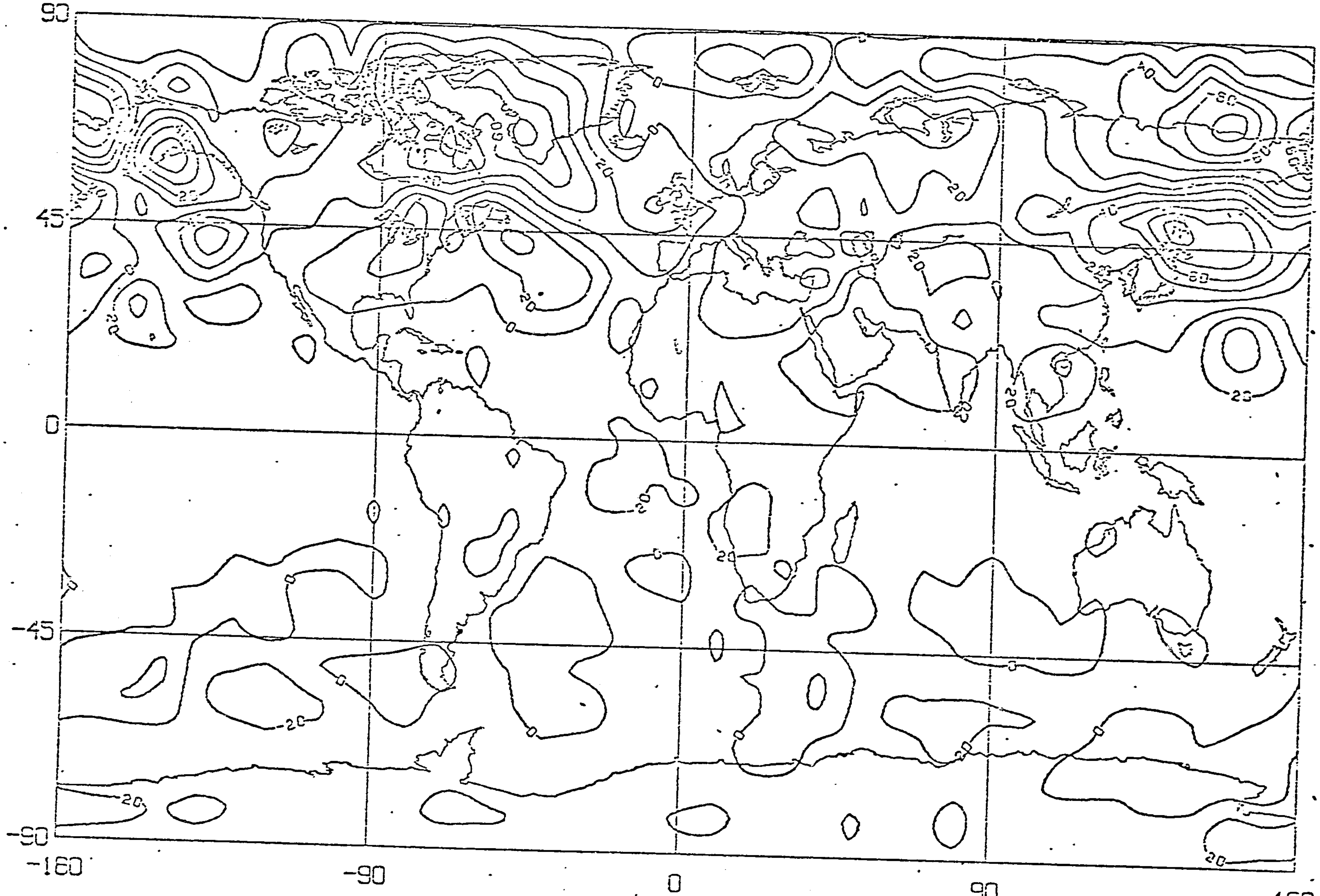
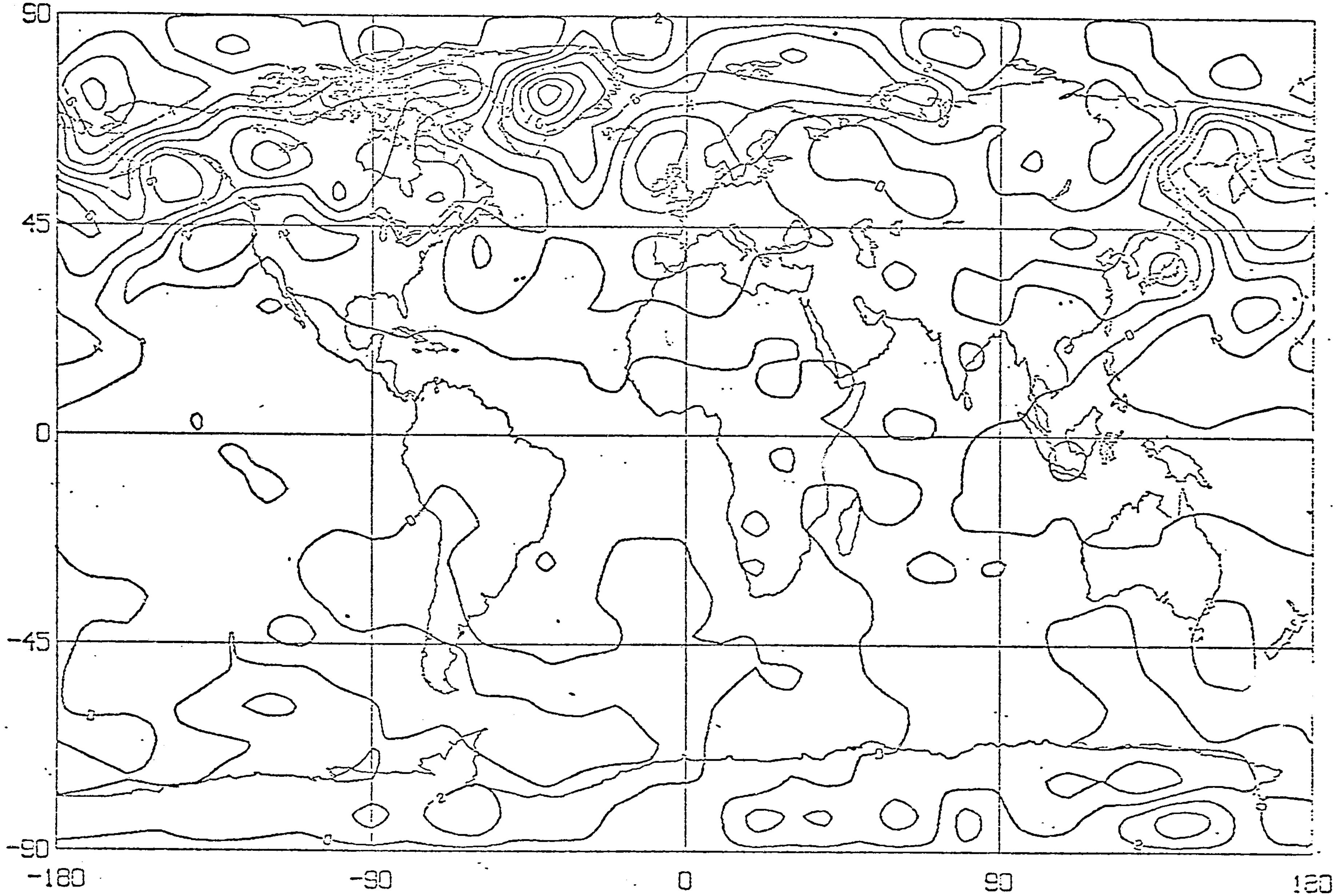


FIGURE 8

ANM-CNT FCSTS SEA LEVEL PRESSURE.



The Model Climatology

The results of the model forecast experiments clearly indicated a need to learn more about the climatology which the model generates. In fact, the evaluation of the model climatology now takes precedence over the admittedly premature monthly mean forecast experiments. Before any more forecasts are attempted, it must be determined whether or not the model produces a realistic climatology. To this end, the MX500M7 model was initialized with NMC/NCAR data for 1 December 1976, and was run for a period of 5 simulated years. The 12 monthly average fields derived from the 5 year simulation are considered to represent the "model climatology".

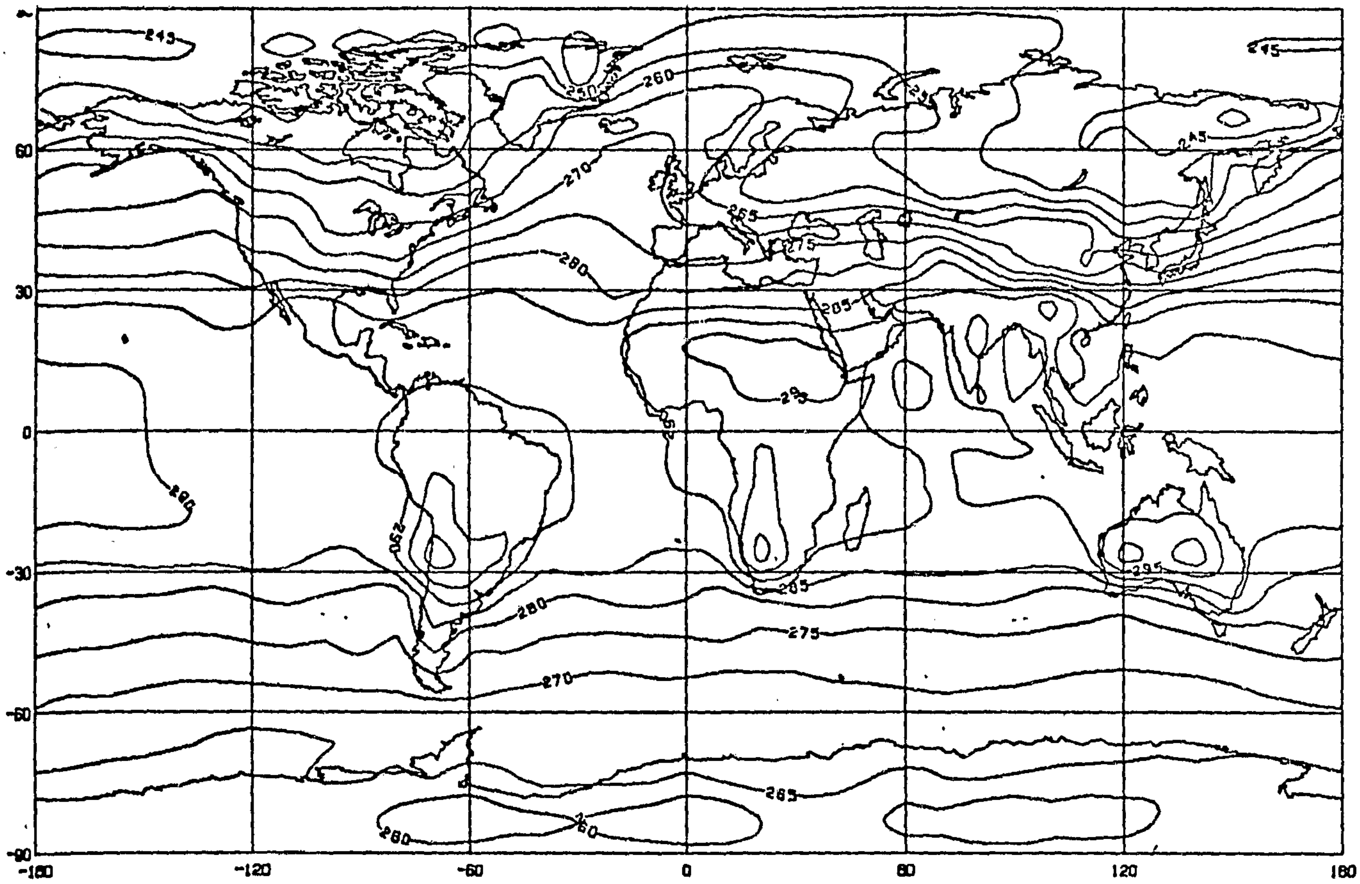
To evaluate the model climatology, it was compared with a climatological data set available on tape from NCAR and based on data archived at NCC. A numerical comparison of the two climatologies is shown in Table 4, in which the bias (algebraic mean difference between model and observed climatology) as well as rms differences and S1 scores are tabulated for 5 months, October - February, for the Northern Hemisphere.

Comparing Table 4 with Table 1, it appears that the discrepancy between the two synoptic climatologies is quantitatively similar to the discrepancy between the forecast and observed monthly mean fields, which does suggest that the forecast errors are associated with "errors" in the model climatology.

The differences between the two climatologies are illustrated in figures 9-11 showing the model climatology (top) and the observed climatology (bottom) for the month of December. While the model climatology is generally rather realistic in appearance, there are some notable differences between the two climatologies, particularly in the SLP field and in the sub-tropical land temperatures in the summer hemisphere,

Table 4. Five-year "model climatology" versus observed (NCAR) climatology difference statistics for the Northern Hemisphere.

Month	Field	Bias	Rms	S1
October	T8	-0.2°C	3.8°C	72
	Z5	-29m	51m	57
	SLP	-1.2mb	6.9mb	98
November	T8	-0.5°C	4.0°C	70
	Z5	-40m	61m	52
	SLP	-1.6mb	6.2mb	89
December	T8	-0.5°C	3.8°C	58
	Z5	-44m	66m	54
	SLP	-2.1mb	6.1mb	87
January	T8	-0.5°C	3.8°C	60
	Z5	-53m	77m	54
	SLP	-2.4mb	6.1mb	89
February	T8	-0.6°C	4.1°C	61
	Z5	-52m	76m	53
	SLP	-2.8mb	6.2mb	91



DECEMBER MODEL CLIMATOLOGY 850MB TEMPERATURE

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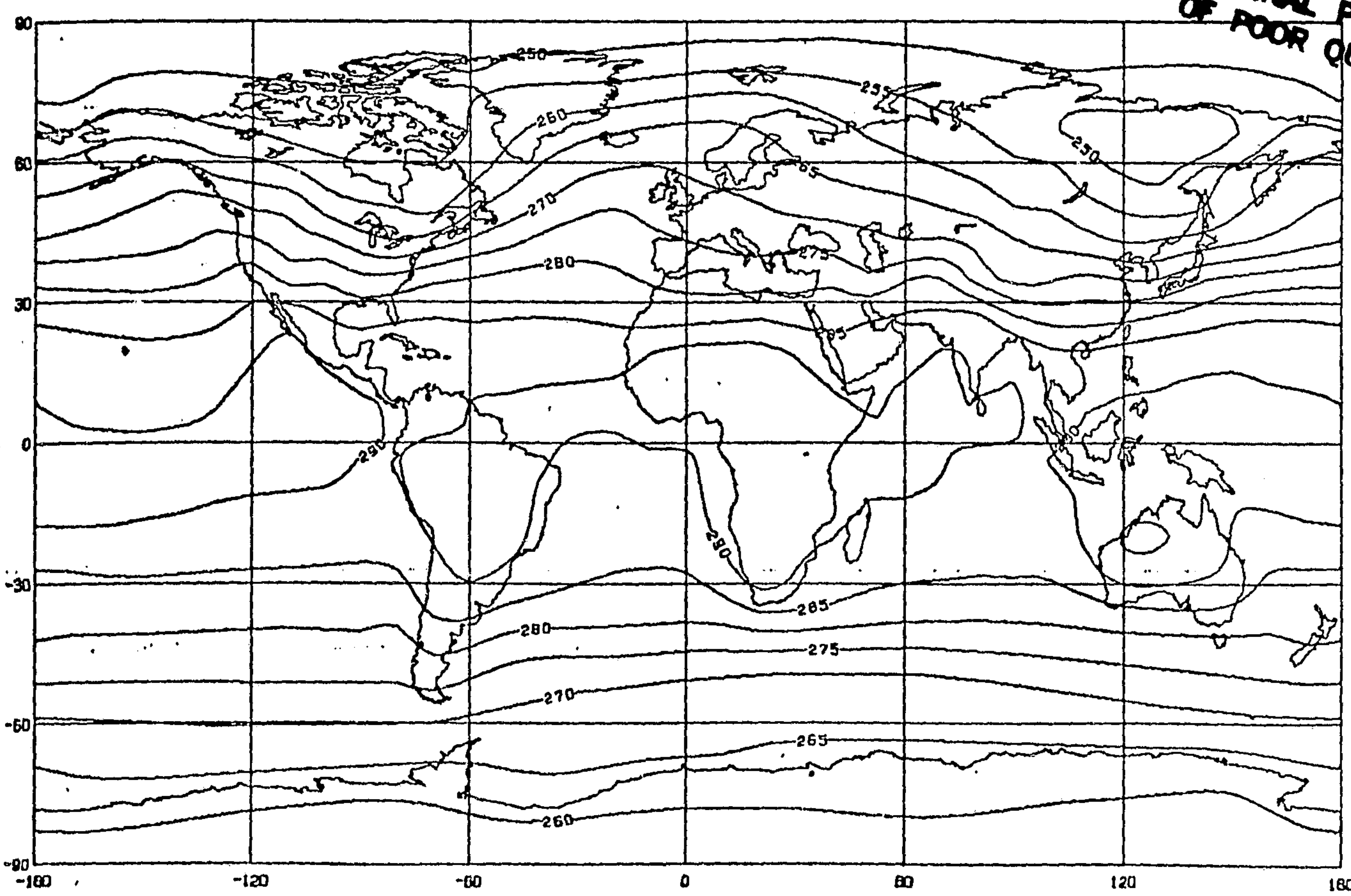
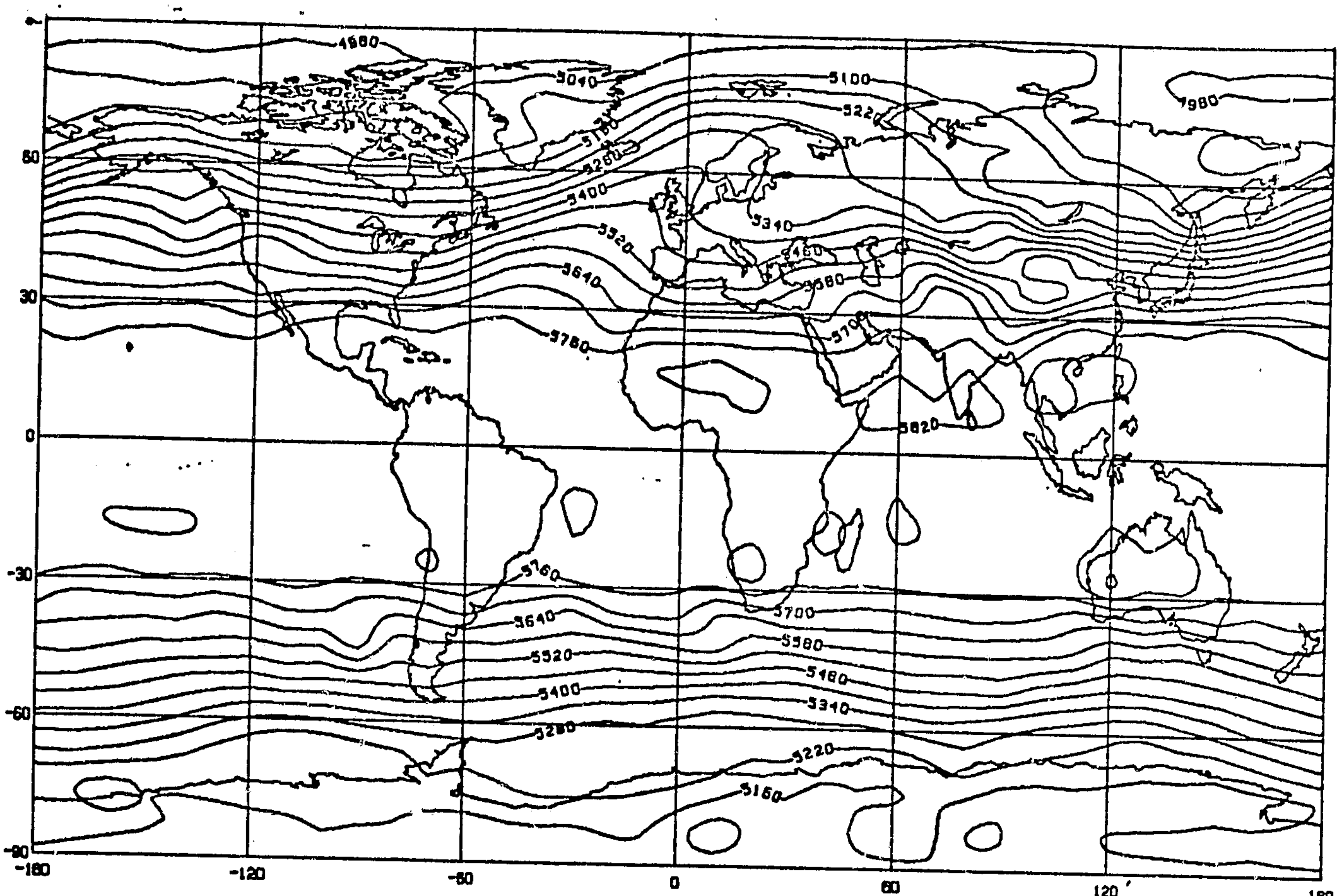
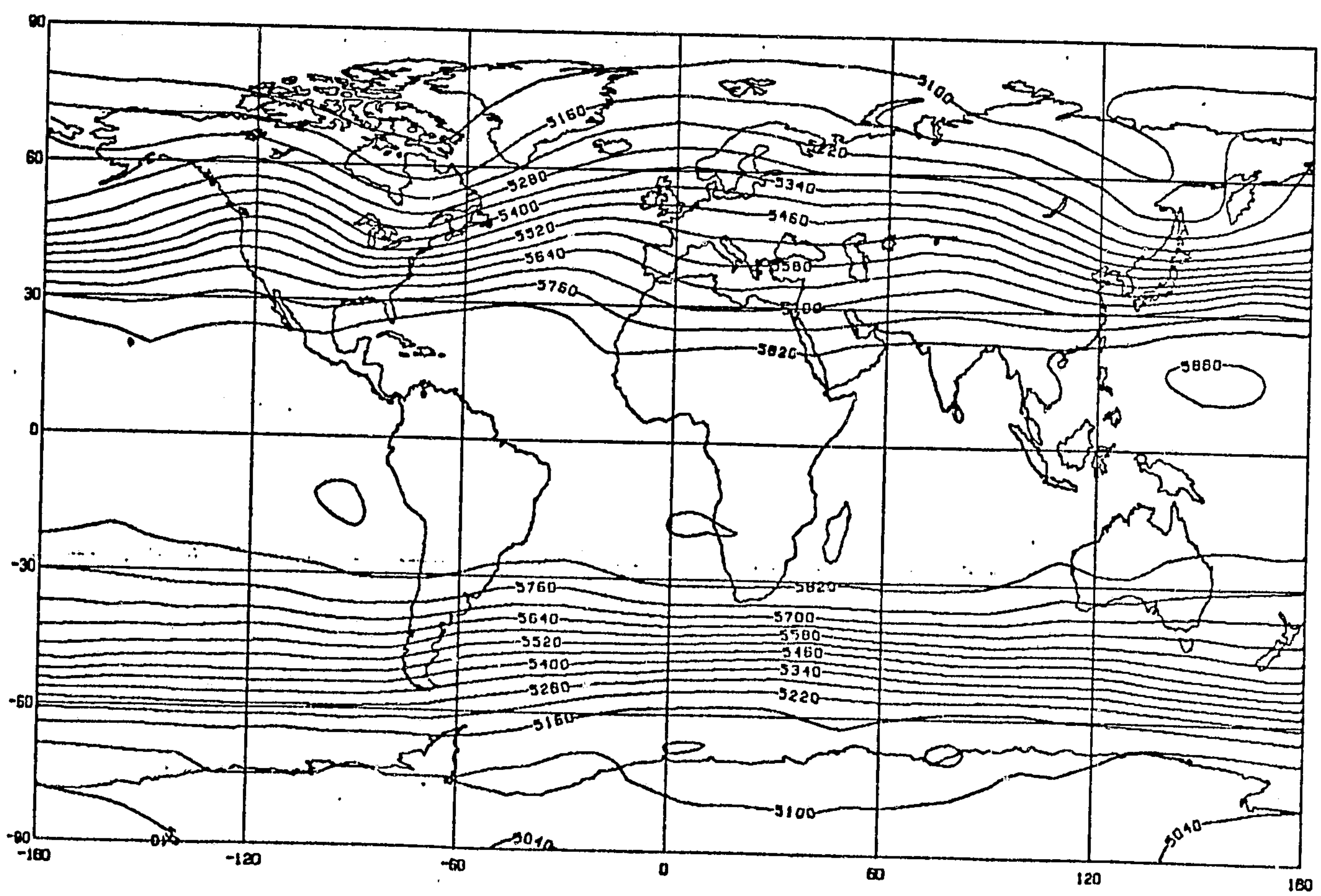


DECEMBER CLIMATOLOGY 850MB TEMPERATURE

Fig. 9

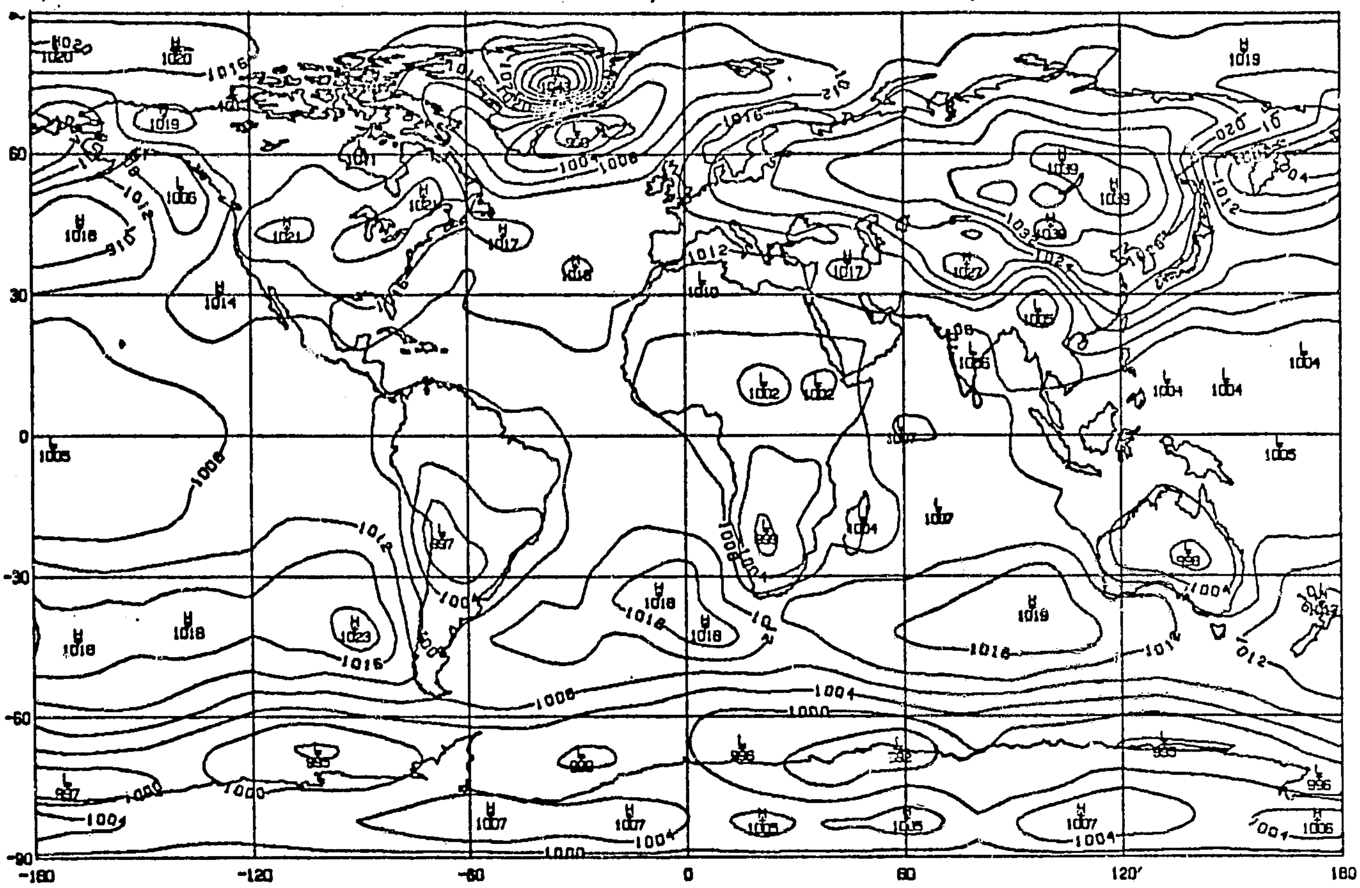


DECEMBER MODEL CLIMATOLOGY 500MB GEOPOTENTIAL HEIGHT

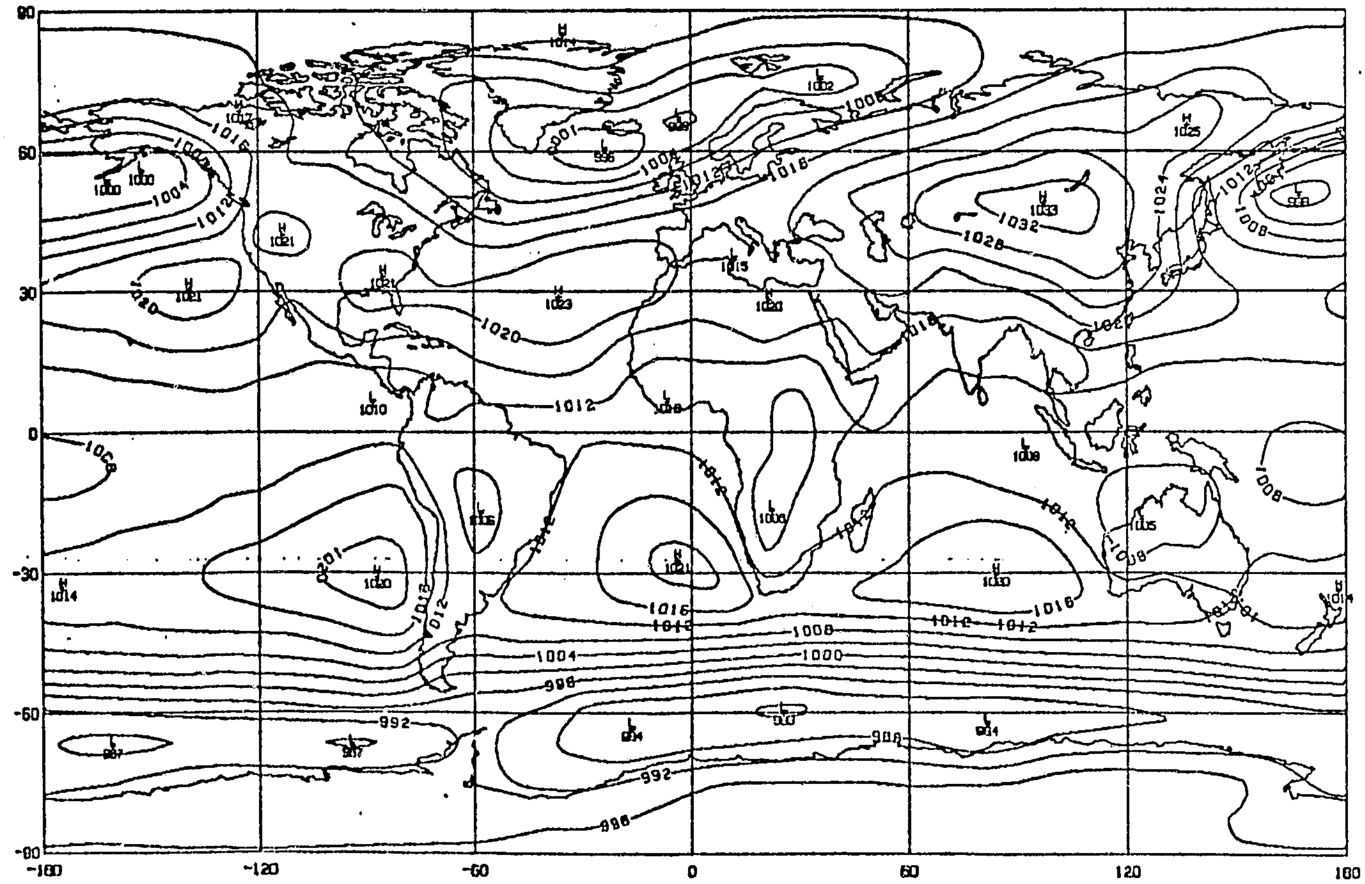


DECEMBER CLIMATOLOGY 500MB GEOPOTENTIAL HEIGHT

Fig. 10



DECEMBER MODEL CLIMATOLOGY SEA LEVEL PRESSURE

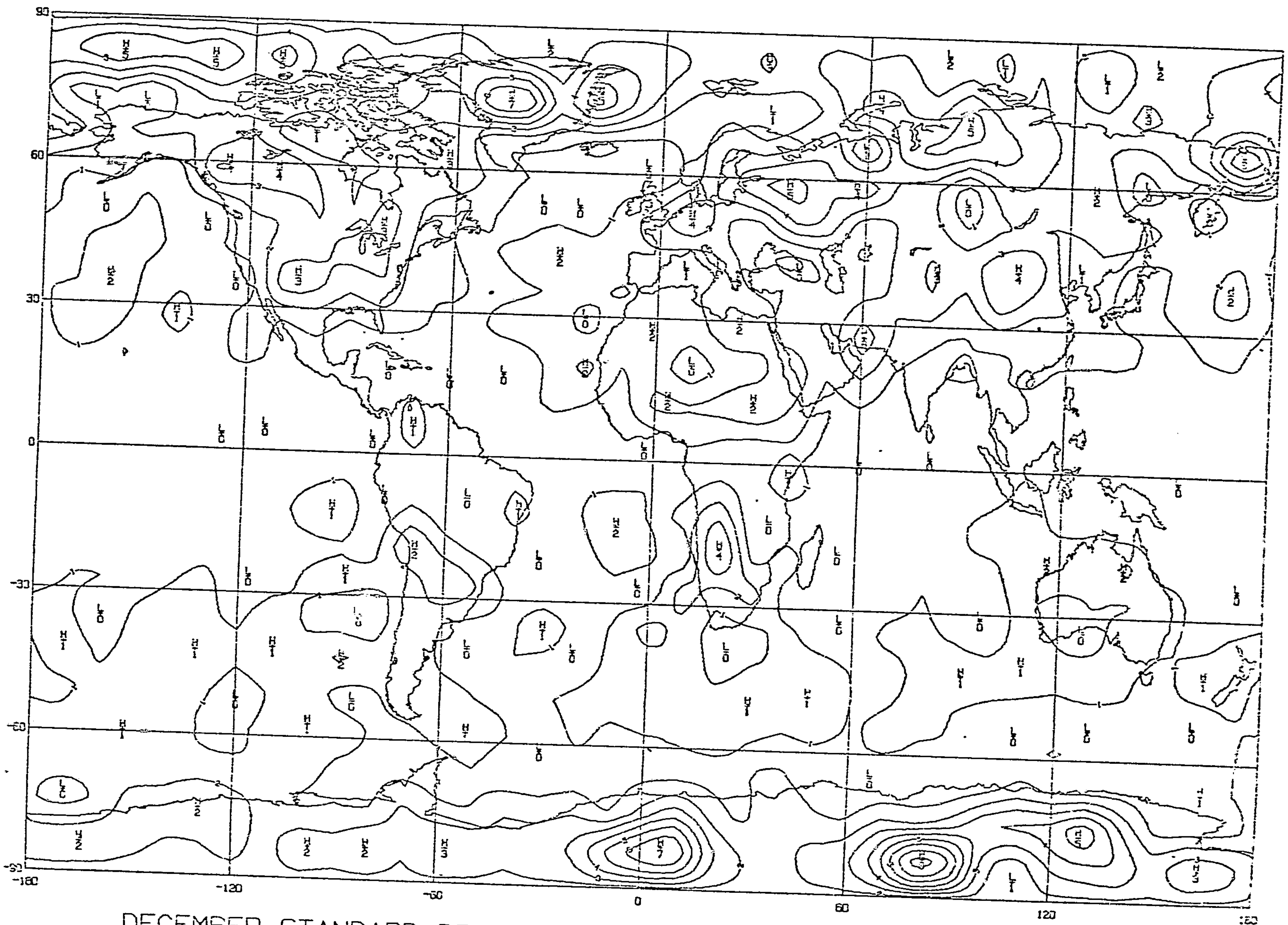


DECEMBER CLIMATOLOGY SEA LEVEL PRESSURE

Fig. 11

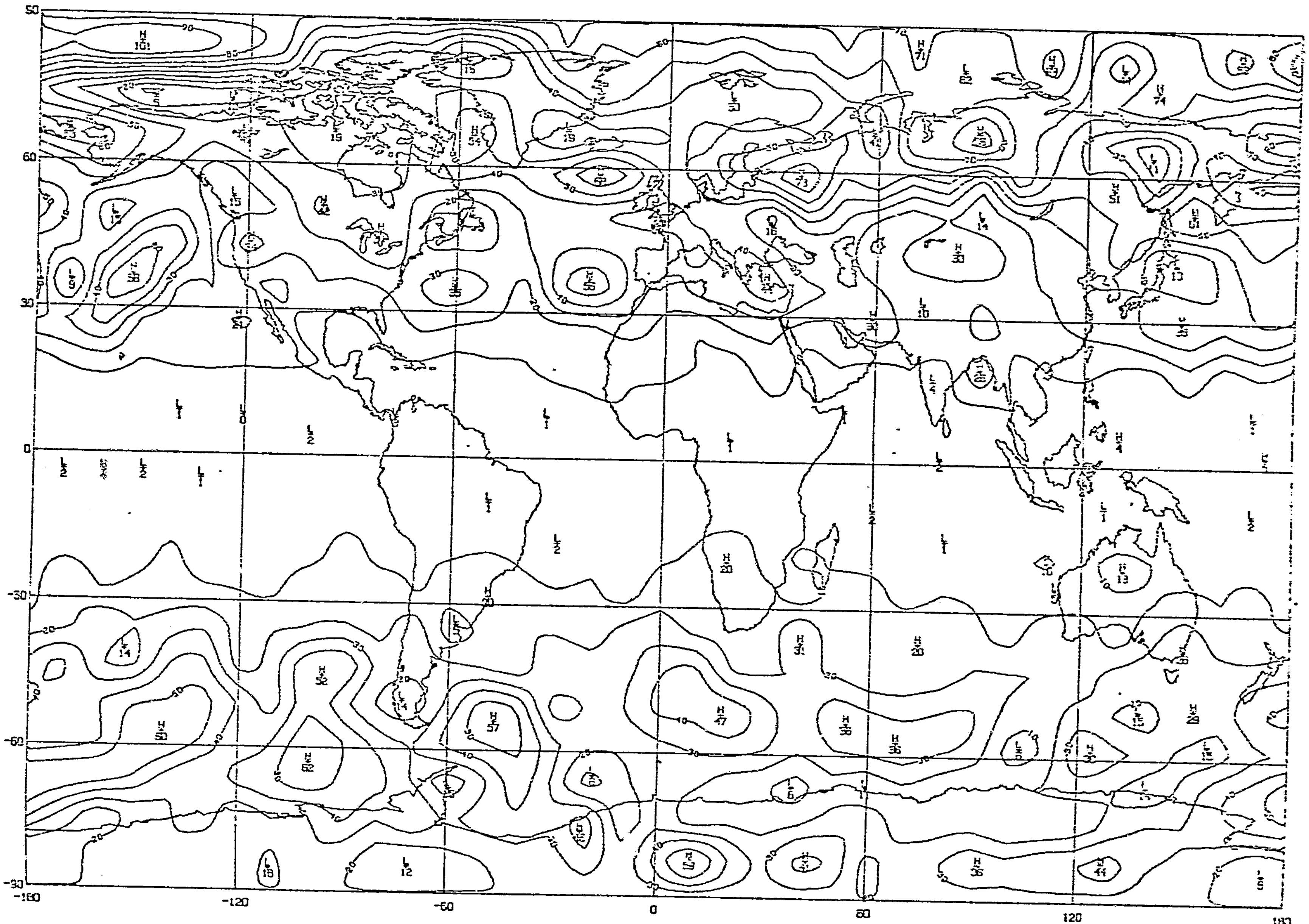
which are too warm in the model simulation.

From the model climatology run it is possible to determine the interannual variances of the model atmosphere for each month. These are illustrated for the month of December in figures 12-14, showing global maps of standard deviations of T8, Z5, and SLP. The magnitudes of the model standard deviations are similar to those of the real atmosphere (e.g., Crutcher and Meserve, 1970), with large values in high latitudes and low values in the tropics. However, the Arctic and Antarctic standard deviations (which are indicative of the model "noise level") appear to be extremely high.



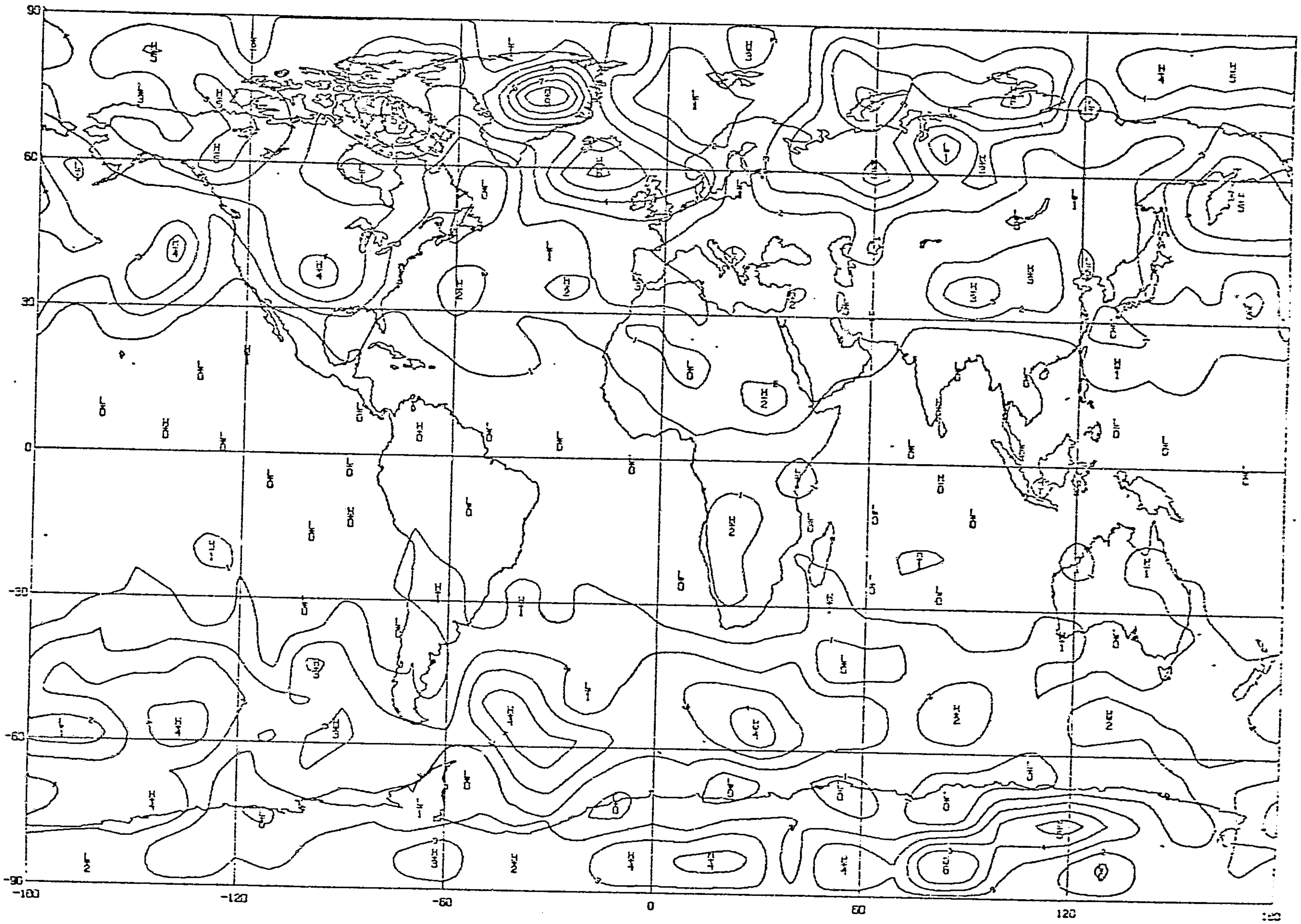
DECEMBER STANDARD DEVIATION 850MB TEMPERATURE

Fig 12



DECEMBER STANDARD DEVIATION 500MB GEOPOTENTIAL HEIGHT

Fig. 13



DECEMBER STANDARD DEVIATION SEA LEVEL PRESSURE

Fig. 14

Spherical Harmonic Analysis

A comparison of model-generated and observed synoptic fields was also carried out in terms of spherical harmonic functions. (See, e.g., Chapman and Bartels, 1962.) In particular, the model-generated and observed monthly climatological fields of T8, Z5 and SLP were subjected to spherical harmonic analysis, and the coefficients ($C_{n,m}$ and $S_{n,m}$) of the even and odd normalized spherical harmonic functions for each month were evaluated up to degree, n, and order, m, equal to 18. Amplitudes ($A_{n,m}^2 = C_{n,m}^2 + S_{n,m}^2$) and phase angles ($B_{n,m} = \tan^{-1} S_{n,m}/C_{n,m}$) were computed for each harmonic, and the fields were compared in terms of the principal modes. The analysis was done using both global data and northern hemisphere data alone, with the latter reflected into the Southern Hemisphere for computational purposes.

Figue 15 illustrates the annual cycle of amplitudes and phases for the Northern Hemisphere of the model (dashed) and observed (solid) climatological fields of T8, Z5, and SLP for one component: $n = 4$, $m = 2$. The 4,2 harmonic has 2 nodal parallels ($n-m = 2$), one in each hemisphere, and a longitudinal wave number (m) of 2, corresponding to the distribution of oceans and continents in the Northern Hemisphere. (However, this is not the dominant harmonic. For T8 and Z5, the dominant mode is the zonal harmonic 2,0, representing the difference between the Equator and the poles.) Although the annual cycle of the model for the 4,2 harmonic does resemble that of the actual climatology, one notable discrepancy is due to the large amplitude which the model generates in T8 and SLP in summer, apparently as a consequence of excessive heating of the continents. (A diagnostic study by L. Druyan at GISS indicates that this may be caused by inadequate treatment of soil moisture.) Except for the transitional seasons, the monsoonal phase shifts of T8

TIME SPECTRA FOR THE COMPONENT 4,2

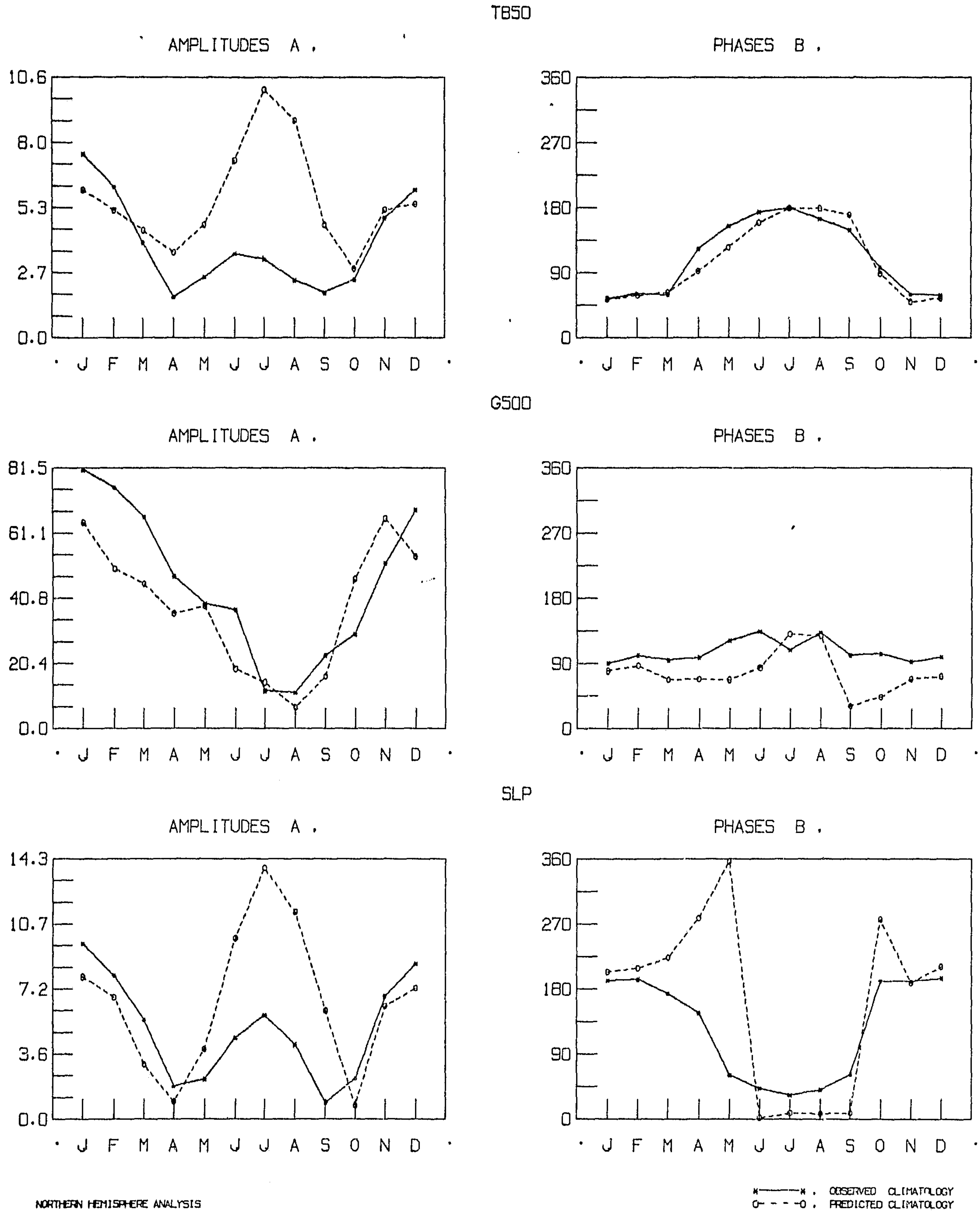


Fig. 15

TIME SPECTRA FOR THE COMPONENT 2,0

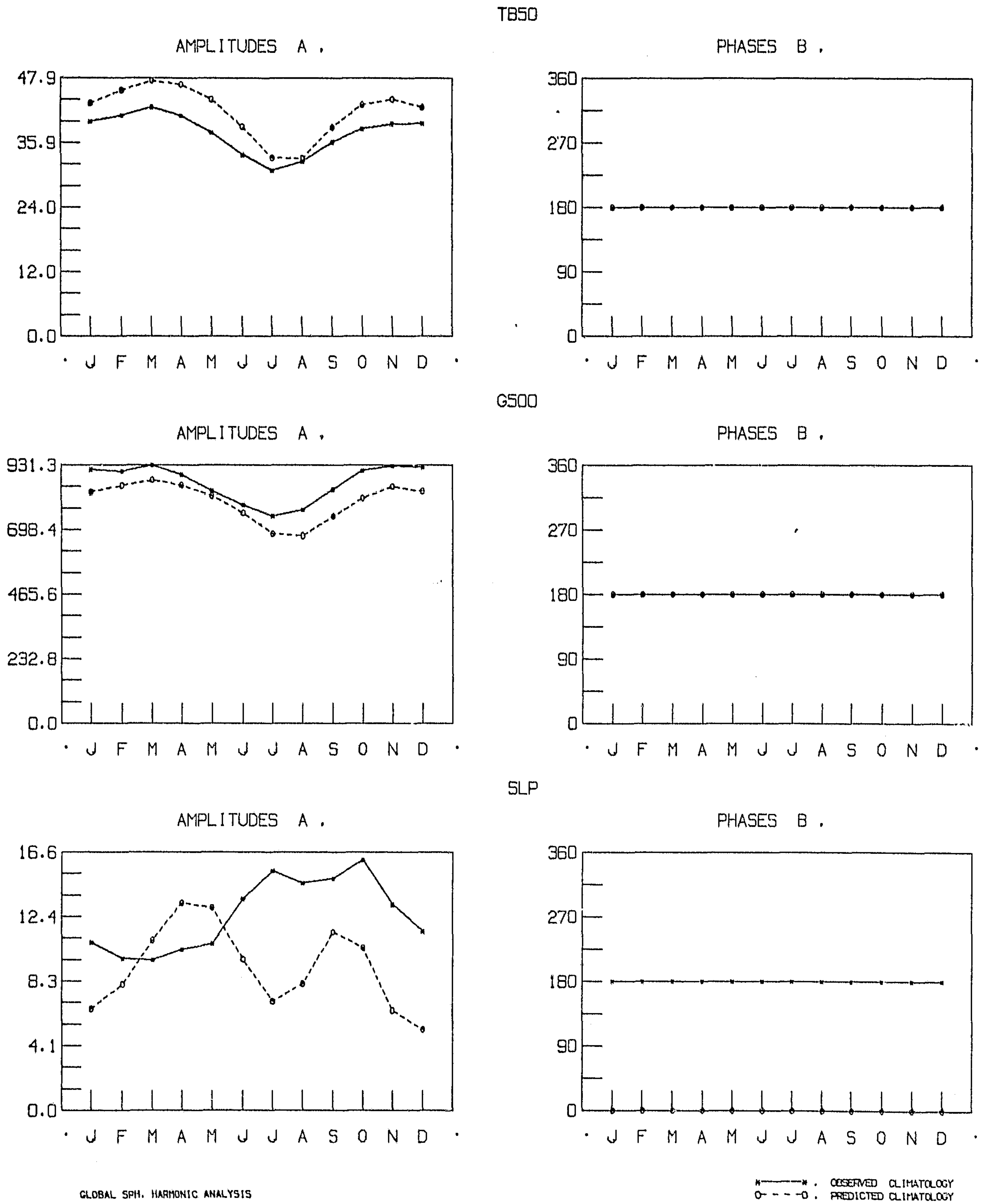


Fig. 16

and SLP are well-represented by the model, and the amplitude cycle for Z5 is quite realistic as well.

The annual cycle of the global Z0 harmonic, shown in figure 16, illustrates the generally good simulation of the meridional profiles of T8 and Z5, and the poor representation of the SLP field. (However, the 2,0 harmonic is not as dominant a component of SLP as of T8 and Z5.)

A comparison can be made between the model and actual climatologies by examining the leading harmonics of the two for any month. In table 5 are listed the first six harmonics (mode, amplitude, phase angle) of the model and NCAR climatologies for the month of December based on the global data and also on data from the Northern Hemisphere alone. (The mean value, represented by the 0,0 harmonic is not included in the list.)

Based on the leading six harmonics for each field shown in Table 5 it is again apparent that the model simulates the T8 and Z5 climatological fields somewhat more successfully than it does the SLP field. Among the global harmonics for T8, four of the six observed modes (2,0; 1,0; 3,2; and 3,1) are found among the first six model harmonics, with approximately correct amplitudes and phases, and the same is true of four of the six observed Z5 harmonics (2,0; 6,0; 4,0; and 4,1). Four of the first six global SLP observed modes (1,0; 2,0; 4,0; and 2,1) are also found among the first six model harmonics, but the amplitudes of two of them (1,0 and 2,0) are not in good agreement. From the Northern Hemisphere harmonics in Table 5, similar conclusions can be drawn. The first three observed hemispheric T8 modes (2,0; 4,2; and 3,1) are found among the first four model harmonics, while five the six leading observed hemispheric Z5 modes (2,0; 6,0; 3,1; 5,3; 6,2) are found among the first six model harmonics,

Table 5. Six highest harmonics (mode, amplitude, phase angle) of the model and NCAR climatologies for December based on both global data and on Northern Hemisphere data only.

		Globe					
T8 model	mode	2,0	1,0	6,0	3,1	3,2	8,0
	A	42.5	11.4	5.1	4.0	3.6	3.3
	B	-	-	-	304	75	-
T8 NCAR	mode	2,0	1,0	2,1	3,2	3,1	5,4
	A	39.5	9.4	3.7	3.3	3.2	2.7
	B	-	-	342	70	310	330
Z5 model	mode	2,0	1,0	6,0	4,0	4,1	6,2
	A	836	130	88	85	53	44
	B	-	-	-	-	16	71
Z5 NCAR	mode	2,0	6,0	4,0	3,0	4,1	2,1
	A	925	125	110	60	54	47
	B	-	-	-	-	28	11
SLP model	mode	1,0	4,0	2,1	2,0	8,0	3,1
	A	11.3	10.9	5.2	5.2	5.0	5.0
	B	-	-	91	-	-	116
SLP NCAR	mode	1,0	2,0	4,0	6,0	3,0	2.1
	A	17.9	11.5	10.7	9.2	5.8	5.2
	B	-	-	-	-	-	88
		Northern Hemisphere only					
T8 model	mode	2.0	3,1	6,0	4,2	7,1	5,3
	A	50.3	7.2	5.8	5.5	5.0	4.9
	B	-	313	-	55	69	270
T8 NCAR	mode	2,0	4,2	3,1	1,1	2,2	6,2
	A	45.1	6.1	5.6	4.7	3.4	3.4
	B	-	59	332	331	57	52
Z5 model	mode	2,0	3,1	6,0	5,1	6,2	5,3
	A	913	90	84	83	77	56
	B	-	354	-	23	75	271
Z5 NCAR	mode	2,0	6,0	3,1	4,2	5,3	6,2
	A	911	109	83	68	59	59
	B	-	-	358	99	309	78
SLP model	mode	2,0	3,1	4,0	4,2	2,2	6,2
	A	14.0	10.3	9.0	7.2	5.5	4.6
	B	-	103	-	210	213	172
SLP NCAR	mode	4,0	4,2	3,1	7,1	6,0	5,1
	A	9.5	8.5	8.3	6.4	6.3	5.1
	B	-	194	105	226	-	169

and in almost the same order. Although the first three observed hemispheric SLP modes are represented among the first four model harmonics, the leading model harmonic (2,0) is not found among the first six observed modes for SLP. For most of the non-zonal harmonics ($m > o$) in Table 5 which appear in both the model and observed lists, the phase angles are in fairly good agreement.

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